Overview of MC models of MPI

Andrzej Siodmok

School of Physics and Astronomy

MANCHESTER 1824

The University of Manchester

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Overview of MC models of MPI

Models on the market:

- General purpose MC event generators:
  - fHerwig/Herwig++
  - Pythia 6/8
  - Sherpa (see Korinna's talk)
- Cosmic ray models:
  - Epos (see Tanguy's talk), QGSJET, SIBYLL
- Small-x:
  - DIPSY (See Leif's)

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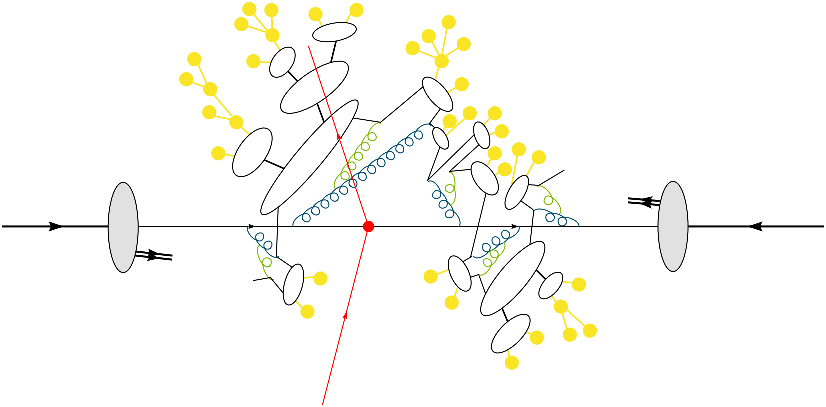
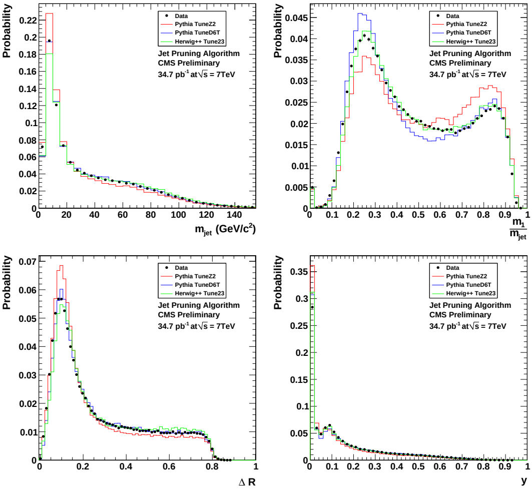
General purpose MC event generators

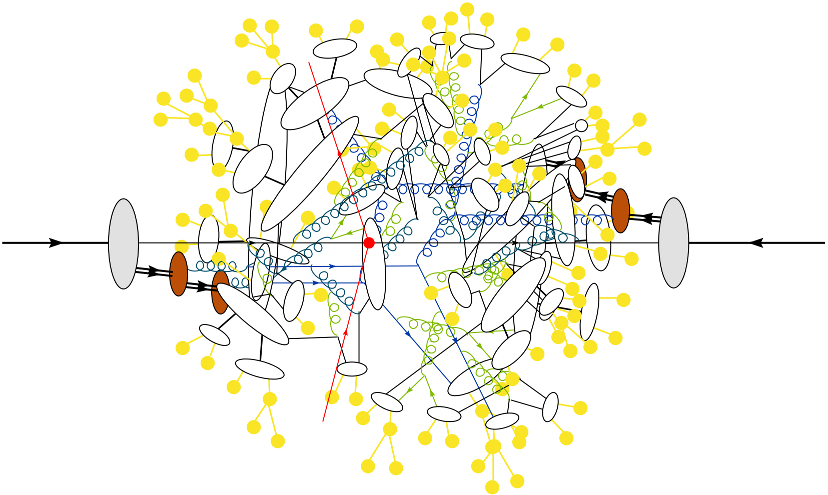


taken from Stefan Gieseke©

Jet pruning/filtering designed to isolate new physics through hard internal jet structure but also a good probe of final state parton shower.
[CMS-PAS-JME-10-013] see Rebecca's talk for more.



General purpose MC event generators



taken from Stefan Gieseke©

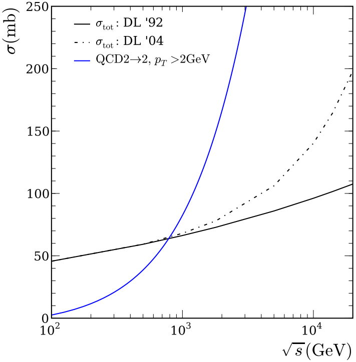
Outline

This talk:

- MPI model basics (we have seen many tunes but what do they mean)
- Remarks on colour reconnection
- Remarks on tuning
- Summary

Inclusive hard jet cross section in pQCD:

$$\sigma^{\rm inc}(s, p_t^{\rm min}) = \sum_{i,j} \int_{p_t^{\rm min\,2}} {\rm d}p_t^2 \int {\rm d}x_1 {\rm d}x_2 \;\; f_i(x_1, Q^2)\, f_j(x_2, Q^2) \;\; \frac{{\rm d}\hat{\sigma}_{ij}}{{\rm d}p_t^2}$$



$\sigma^{\rm inc} > \sigma_{\rm tot}$ eventually

Interpretation:

- $\sigma^{\rm inc}$ counts all partonic scatters in a single *pp* collision
- more than a single interaction

$$\sigma^{\rm inc} = \langle n_{\rm dijets} \rangle \sigma_{\rm inel}$$

- direct evidence: measurement of momentum imbalance in multijet events at CERN ISR, $\gamma + 3$ jet at TVT.

MPI model basics (Herwig++)

Assumptions:

- the distribution of partons in hadrons factorizes with respect to the b and x dependence ⇒ average number of parton collisions:

$$\begin{aligned}
\bar{n}(\vec{b}, s) &= L_{\text{partons}}(x_1, x_2, \vec{b}) \otimes \sum_{ij} \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&= \sum_{ij} \frac{1}{1+\delta_{ij}} \int \mathrm{d}x_1 \mathrm{d}x_2 \int \mathrm{d}^2\vec{b}' \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&\quad \times D_{i/A}(x_1, p_t^2, |\vec{b}'|) D_{j/B}(x_2, p_t^2, |\vec{b} - \vec{b}'|) \\
&= \sum_{ij} \frac{1}{1+\delta_{ij}} \int \mathrm{d}x_1 \mathrm{d}x_2 \int \mathrm{d}^2\vec{b}' \int \mathrm{d}p_t^2 \frac{\mathrm{d}\hat{\sigma}_{ij}}{\mathrm{d}p_t^2} \\
&\quad \times f_{i/A}(x_1, p_t^2) G_A(|\vec{b}'|) f_{j/B}(x_2, p_t^2) G_B(|\vec{b} - \vec{b}'|) \\
&= A(\vec{b}) \sigma^{\text{inc}}(s; p_t^{\text{min}}) \,.
\end{aligned}$$

- at fixed impact parameter b, individual scatterings are independent (leads to the Poisson distribution)

Matter distribution

Average number of parton collisions

$$\bar{n}(b,s) = A(b) \cdot \sigma^{\text{inc}}(s, p_t^{\text{min}})$$

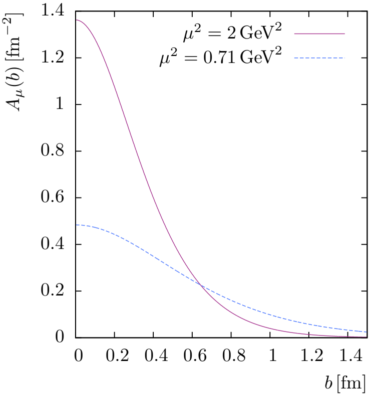
$$A(b,\mu) = \int \mathrm{d}^2 b' \; S_A(\mathbf{b}') \; S_B(\mathbf{b} - \mathbf{b}')$$

$S(\mathbf{b})$ from electromagnetic FF:

$$S_p(\mathbf{b}) = S_{\bar{p}}(\mathbf{b}) = \int \frac{\mathrm{d}^2 k}{(2\pi)^2} \frac{\mathrm{e}^{i\mathbf{k}\cdot\mathbf{b}}}{(1+\mathbf{k}^2/\mu^2)^2}$$

But μ^2 *not fixed* to the *electromagnetic* $0.71\,\text{GeV}^2$.

Free for colour charges.



⇒ Two main parameters: μ^2 and p_t^{min}

Pythia: Few functions including x-depended overlap

[Corke, Sjostrand, JHEP 1105:009], Richard's talk from MPI2010

Hot Spot model (soft MPI)

So far: hard multiple interactions

Extension to soft interactions with

$$\bar{n}(b,s) = \left(A(b,\mu)\sigma^{\rm inc}_{\rm hard}(s,p_t^{\rm min}) + A(b,\mu_{\rm soft})\sigma^{\rm inc}_{\rm soft}\right)$$

Require simultaneous description of $\sigma_{\rm tot}$ and $b_{\rm el}$ (measured/well predicted),

$$\sigma_{\rm tot}(s) \stackrel{!}{=} 2\int {\rm d}^2b \left(1 - {\rm e}^{-\chi_{\rm tot}(b,s)}\right) ,$$

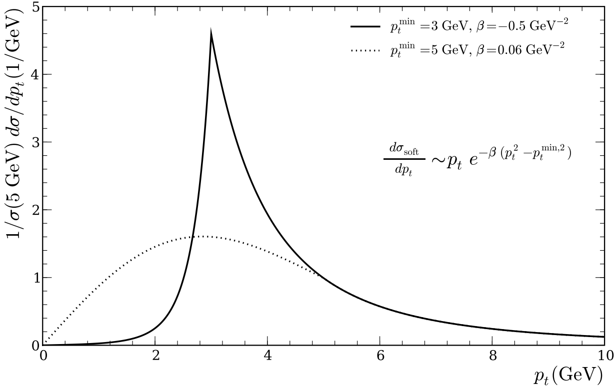
$$b_{\rm el}(s) = \left[\frac{\rm d}{{\rm d}t}\left(\ln\frac{{\rm d}\sigma_{\rm el}}{{\rm d}t}\right)\right]_{t=0} \stackrel{!}{=} \int {\rm d}^2b \frac{b^2}{\sigma_{\rm tot}}\left(1 - {\rm e}^{-\chi_{\rm tot}(b,s)}\right) .$$

$\Rightarrow$ This fixes the two parameters $\mu_{\rm soft}$ and $\sigma^{\rm inc}_{\rm soft}$

Only free parameters in the end: $p_t^{\rm min}$ and μ^2

Extension to soft MPI, $p_t < p_t^{\min}$

Continuation of the differential cross section into the soft region $p_t < p_t^{\min}$ (here: p_t integral kept fixed)



Pythia: Regularise cross section by introducing $p_{\perp 0}$:

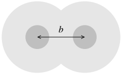
$$\frac{\alpha_s^2(p_\perp^2)}{p_\perp^4} \to \frac{\alpha_s^2(p_{\perp 0}^2 + p_\perp^2)}{\alpha_s^2(p_\perp^2)} \frac{p_\perp^4}{(p_{\perp 0}^2 + p_\perp^2)^2}$$

From Hans Van Haevermaet:

Phenomenology of multi-parton interactions

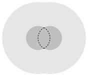
- The number of interactions depends on
  - ➔ the p_T scale of the event
  - ➔ the centre-of-mass energy: increase of particle densities

Minimum bias



Peripheral collision
few MPI

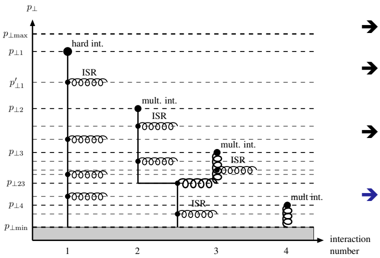
Hard scale $\hat{p}_T$



Central collision
many MPI

[Phys. Rev. D83 (2011) 054012]

- Introduce a MPI model to describe the soft interactions: extend hard scatter cross section to low p_T



[arXiv:hep-ph/0601012]

➔ But divergence: $1/\hat{p}_T^4$ if $\hat{p}_T \to 0$

➔ Introduce regularization:

$$1/\hat{p}_T^4 \to 1/(\hat{p}_T^2 + \hat{p}_{T,0}^2)^2$$

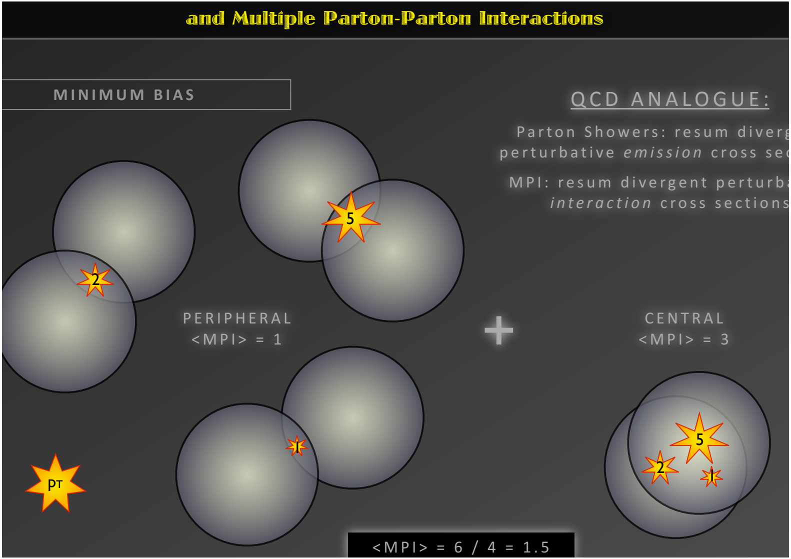
➔ Which is energy dependent:

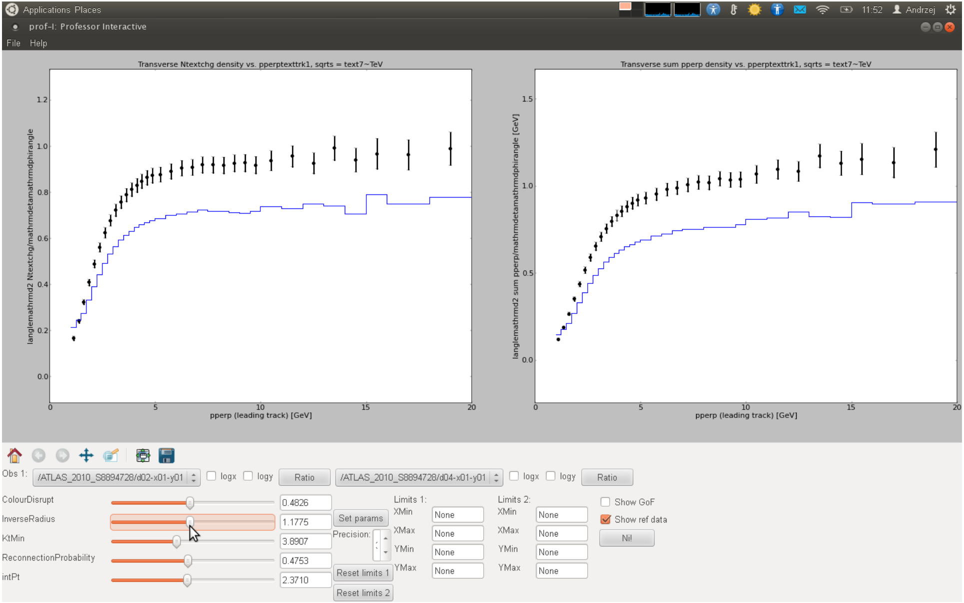
$$\hat{p}_{T,0}(\sqrt{s}) = \hat{p}_{T,0}(\sqrt{s_0}) \cdot (\sqrt{s}/\sqrt{s_0})^{\varepsilon}$$

➔ At a fixed √s, more MPI activity is predicted for smaller values of $\hat{p}_{T,0}$

Semi hard underlying event

Taken from Peter Skands:





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Andrzej
prof-I: Professor Interactive
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pperp (leading track) [GeV]
Transverse sum pperp density vs. pperptexttrk1, sqrts = text7~TeV
langlemathrmd2 sum pperp/mathrmdetamathrmdphirangle [GeV]
pperp (leading track) [GeV]
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logy
Ratio
/ATLAS_2010_S8894728/d04-x01-y01
logx
logy
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InverseRadius
1.1775
Set params
KtMin
3.8907
Precision:
ReconnectionProbability
0.4753
intPt
2.3710
Reset limits 1
Reset limits 2
Limits 1:
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XMax None
YMin None
YMax None
Limits 2:
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Show ref data
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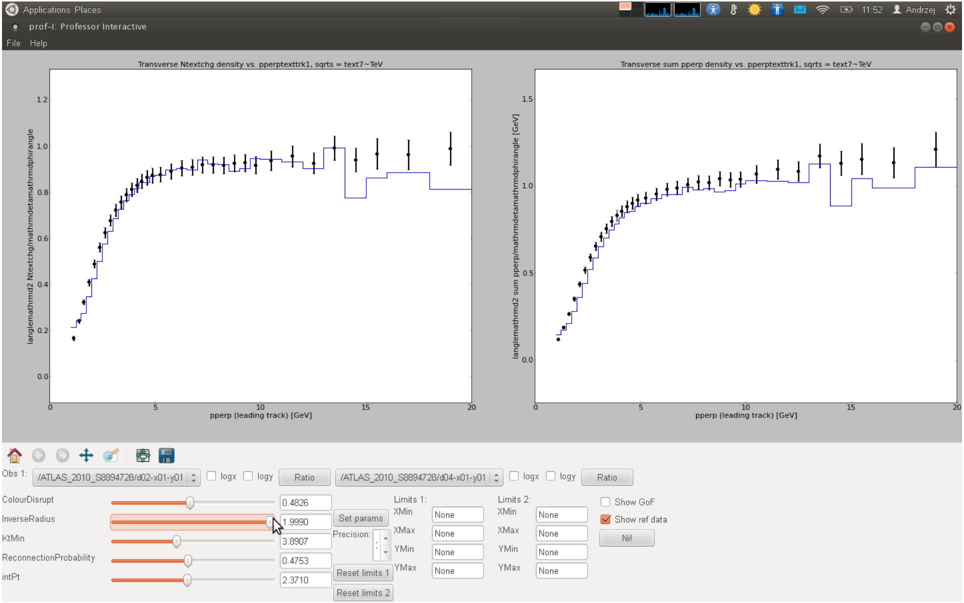
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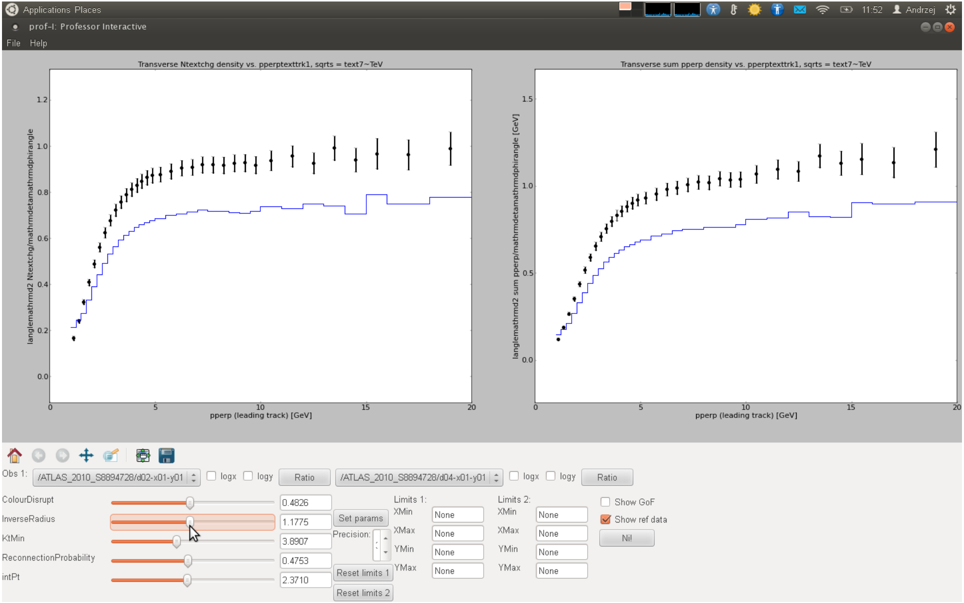

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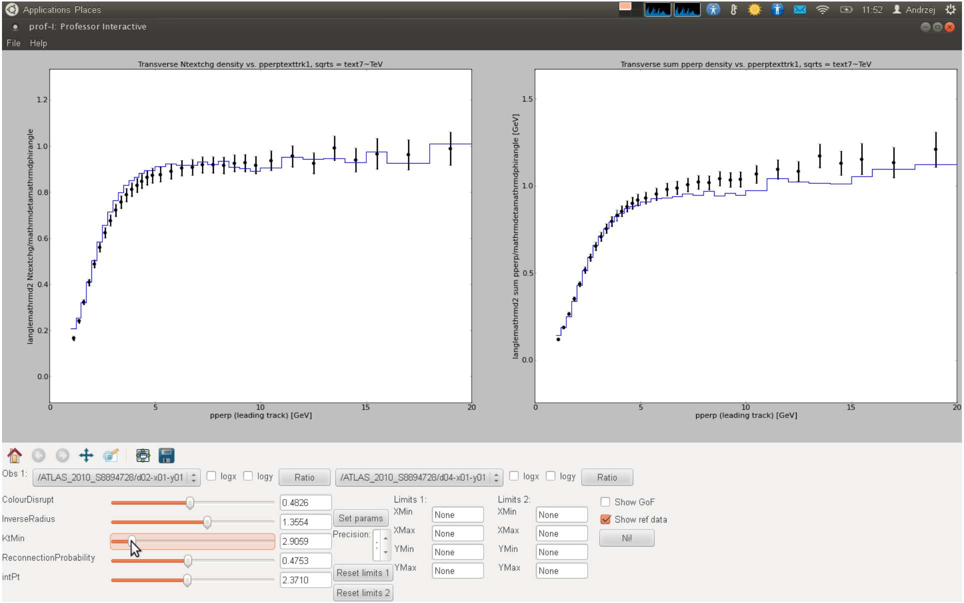
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Limits 2:
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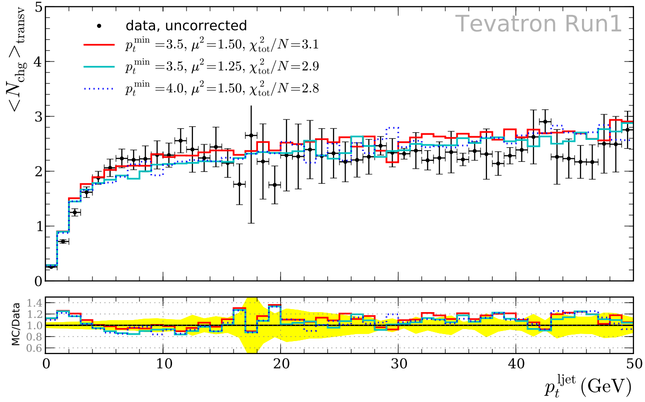
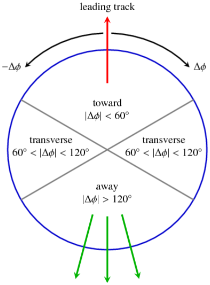
XMax None
YMin None
YMax None
Show GoF
Show ref data
Nil

This is enough to describe TVT UE

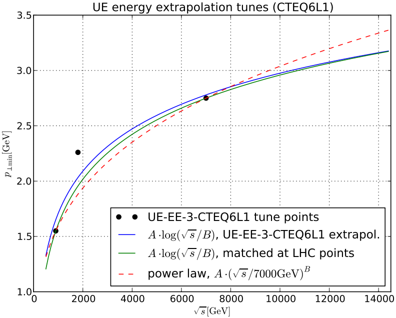




Only two parameters: $p_t^{\min}$ and μ^2

Underlaying Event - Energy interpolation Herwig++

- Not possible to fit with energy-independent parameters (different parameters for different energies).
- Possible to fit with energy-dependent $p_t^{\min}$ and all else energy-independent.
- Interpolation to $\sqrt{s} = 2760$ GeV



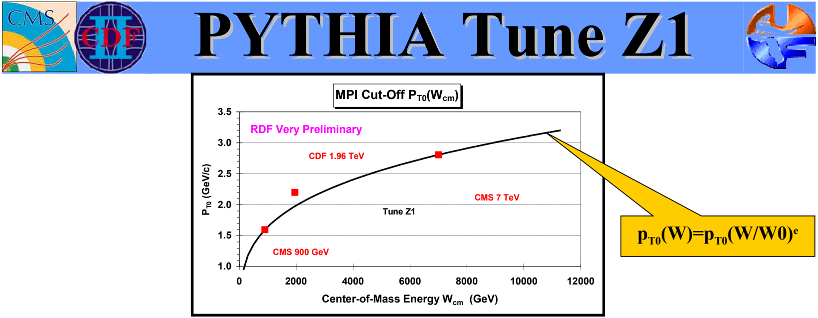
For PDF	CTEQ6L1	MRST LO**
μ^2	1.35	1.11
p_{reco}	0.61	0.54
p_{CD}	0.75	0.80

For PDF For $\sqrt{s}$ =	CTEQ6L1 $p_t^{\min}$	MRST LO** $p_t^{\min}$
900	1.55	1.86
1800	2.26	2.55
2.76	2.33	2.62
7000	2.75	3.06
8000	2.85	3.21
14000	3.16	3.53

Underlaying Event - Energy interpolation Pythia Tune Z1

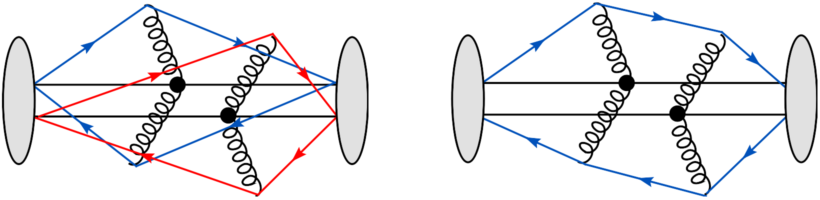
Similar energy dependence in Pythia.

New results from Tevatron energy scan ⇒ better energy extrapolation 13 TeV (see Rick's talk)



Remarks on colour reconnection in hadron collisions

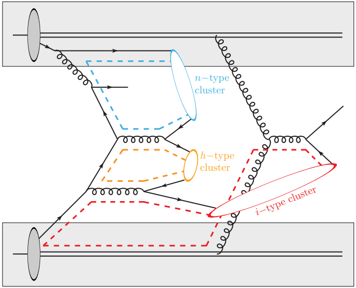
Colour Structure of the Underlying Event multiple interactions, even when soft, can cause non-trivial changes to the colour topology of the colliding system as a whole, with potentially major consequences for the particle multiplicity in the final state

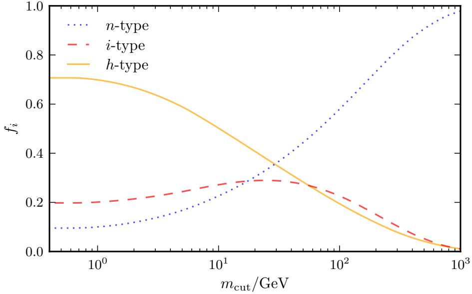


- colour connections to proton remnants
- MPI leads to even more colour charge
- shorten string length $\hat{=}$ reduce cluster masses
  $\hat{=}$ mimic preconfinement

Colour reconnections in Herwig++ [Gieseke, Röhr, AS, Eur.Phys.J. C72 (2012) 2225]

$$f_a(m_{cut}) \equiv N_a(m_{cut}) / \sum_{b=h,i,n} N_b(m_{cut}) = \frac{N_a(m_{cut})}{N_{cl}}\,, \qquad (1)$$





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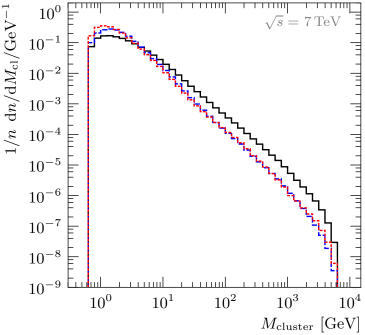
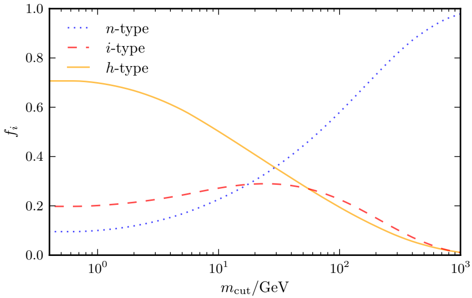
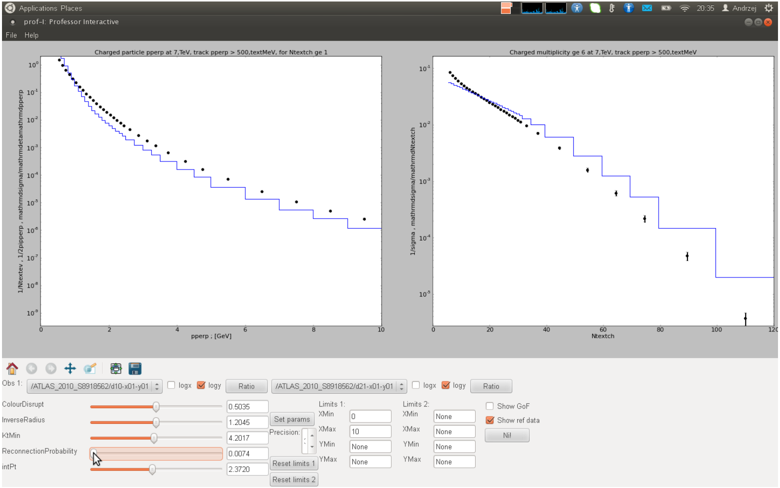




Since these n-clusters can lie at very different rapidities (the extreme case being the two opposite beam remnants), the strings or clusters spanned between them can have very large invariant masses (though normally low $p_\perp$), and give rise to large amounts of (soft) particle production.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pperp ; [GeV]
Charged multiplicity ge 6 at 7,TeV, track pperp > 500,textMeV
1/sigma , mathrmdsigma/mathrmdNtextch
Ntextch
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logy
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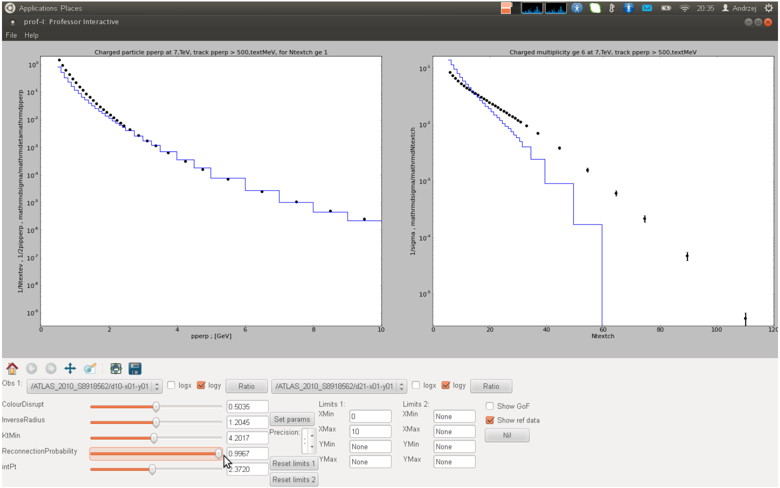
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Charged particle pperp at 7,TeV, track pperp > 500,textMeV, for Ntextch ge 1
1/Ntextev , 1/2pipperp , mathrmdsigma/mathrmdetamathrmdpperp
pperp ; [GeV]
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1/sigma , mathrmdsigma/mathrmdNtextch
Ntextch
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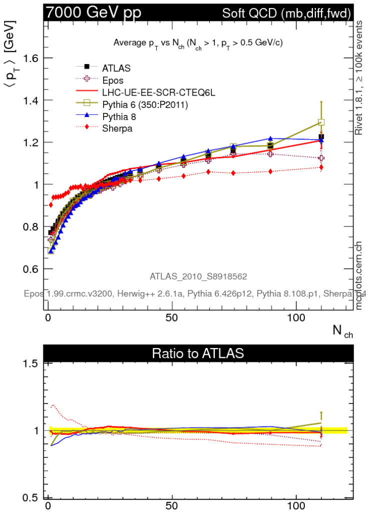

7000 GeV pp
Soft QCD (mb,diff,fwd)
Average p_T vs N_ch (N_ch > 1, p_T > 0.5 GeV/c)
ATLAS
Epos
LHC-UE-EE-SCR-CTEQ6L
Pythia 6 (350:P2011)
Pythia 8
Sherpa
⟨ p_T ⟩ [GeV]
Rivet 1.8.1, ≥ 100k events
ATLAS_2010_S8918562
Epos 1.99.crmc.v3200, Herwig++ 2.6.1a, Pythia 6.426p12, Pythia 8.108.p1, Sherpa 1.4
mcplots.cern.ch
N_ch
Ratio to ATLAS

Colour Reconnection model tests

We used two LEP analyses (sensitive to color reconnection) to test the new model:

- OPAL Collaboration arXiv:hep-ex/0306021v1:

  "Tests of models of color reconnection and a search for glueballs using gluon jets with a rapidity gap"

- DELPHI Collaboration, Eur. Phys. J. C51 (2007) 249-269],
  particles flow in $WW \to 4j$ at LEP

Result:

- Herwig++ with and w/o colour rec. seems to describe these data sets at the same level.

Tuning remarks: tunes from mcplots-dev.cern.ch

Sherpa 1.4.0

1. default

Herwig++ 2.6.1a

1. LHC-UE-EE-4
2. LHC-UE-EE-4-CTEQ6L1
3. LHC-UE-EE-SCR-CTEQ6L

Pythia 8.170

1. default
2. default-CD
3. default-MBR
4. default-noFsr
5. default-noRap
6. early
7. tune-1
8. tune-2c
9. tune-2m
10. tune-4c
11. tune-4cx
12. tune-A2

Pythia 6.426p12

1. 350
2. 351
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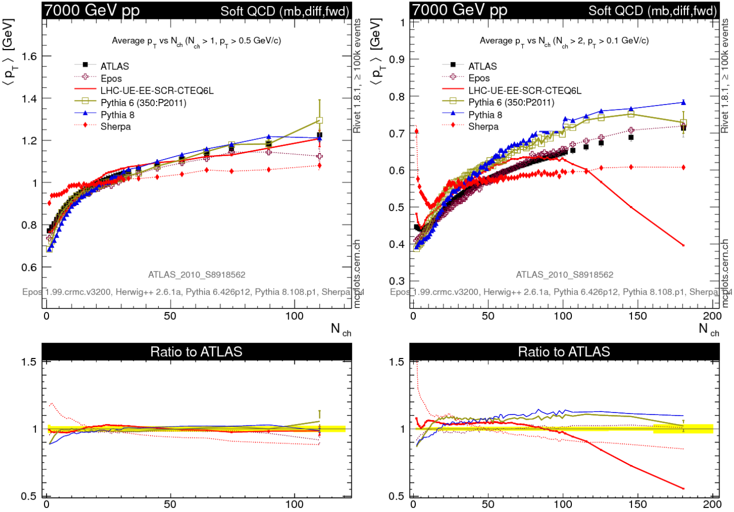
24. 377
25. 378
26. 379
27. a
28. ambt1
29. atlas-csc
30. d6t
31. default
32. dw
33. dwt
34. p0
35. p2010
36. p3
37. p6
38. phard
39. pnocr
40. pro-q2o
41. psoft
42. px
43. z1
44. z1-lep
45. z2
46. z2-lep

MB 7000 TeV, problem at low p_T, high Nch:



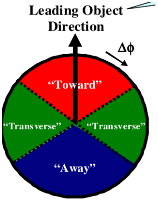
Tuning - remarks

- A lot of nice/precise/challenging LHC data sets:
  - Alice: “Measuring ’minijets’ using two-particle angular correlations” see Eva’s talk
  - LHCb: (Prompt hadron production ratios), see Andrea’s talk
  - CMS: Measurements of the energy flow and UE behavior at forward rapidities, see talk by Hans
  - ATLAS: UE results, see Depak’s talk.
  - ...
- Help with tuning from experimental collaborations is very welcome!
- Analysis in Rivet is very helpful (see next slide).
- Does MPI need a different tuning for MC setups where the shower and MPI generation is matched to a NLO ME generator? I general, we should use as much physics as we can in order to not over tune.
- Identified Particles Ratios (missing physics model? different hadronization model? cluster)

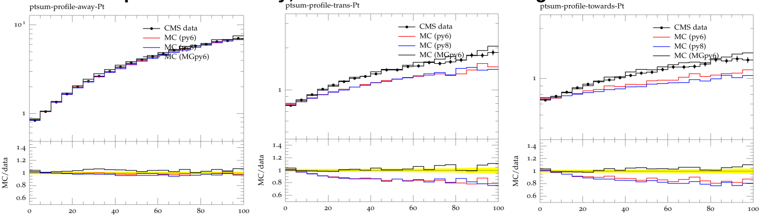
Taken from P. Lenzi talk.

UE in DY

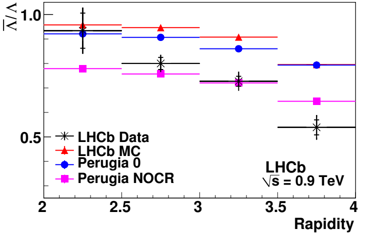
- Classic Rick Field UE observable, using the Z as "leading object"
- We are looking at the hadronic recoil
  - Similar to what you do with Zpt
  - **But this time differentially in terms of how the phase space for the recoil is filled**
- Pythia is able to describe only the away region
  - Z+1jet topology
- **Already at 20 GeV Zpt you need ME+PS if you want to describe the "transverse" and "toward" regions**
  - **Might be relevant for MET**

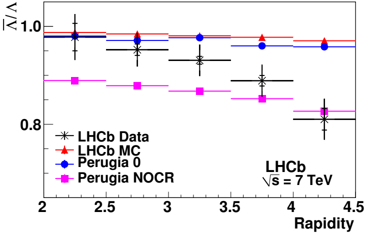


Σ track pT vs Z Pt in away, transverse and towards regions



Prompt hadron productio





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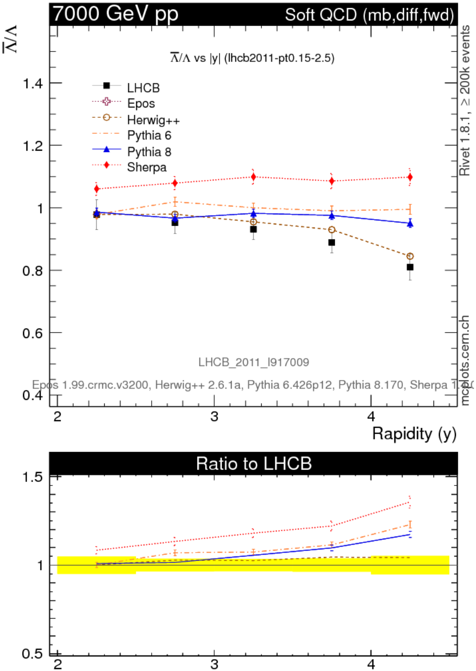
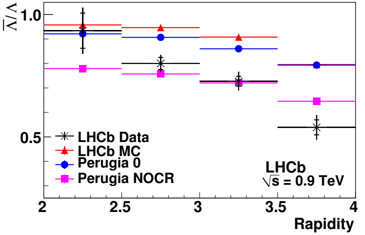
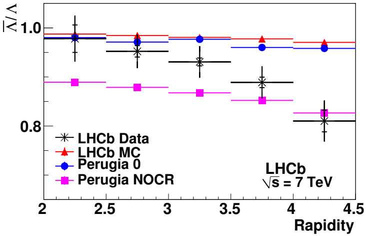


Prompt hadron productio





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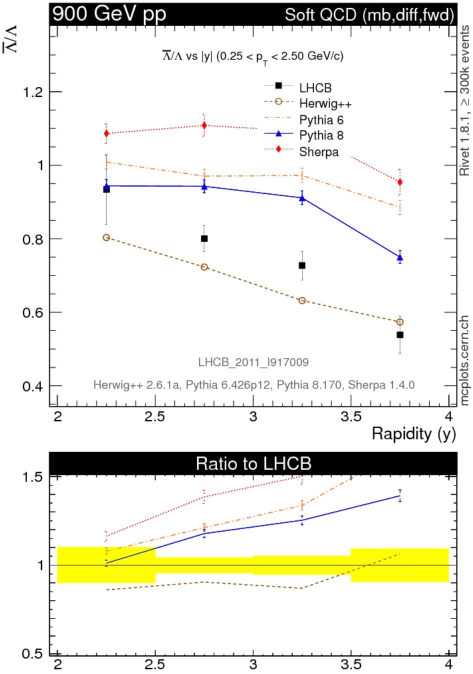
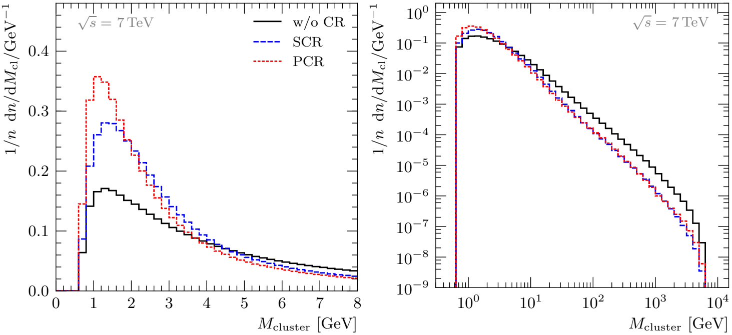


Summary

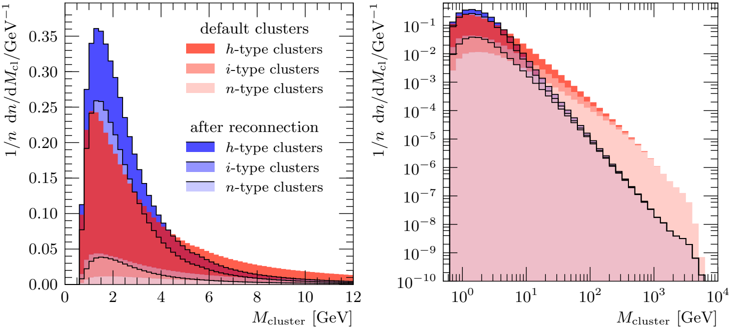
- Not-too-soft not-too-high-multiplicity physics under good control.
- A lot of nice/precise LHC data sets - useful for improvements of MPI models.
- Different MPI models on the market (famous from soft QCD Pythia 6/8, Herwig++ (diffraction under construction), Sherpa (w/o CR), Epos, ... more under construction DIPSY, SHRiMPS) - use at least two different models (not tunes!) to see what impact MPI has on your analysis. We have seen talks with results compared to few models - very good job!
- Plots and tunes: mcplots.cern.ch (for more recent/less tested mcplot-dev.cern.ch)
- Minimum bias/underlying event/diffraction under constant improvement!
- It is recommended to use recent tunes.
- Still many questions to be answer, for example: σ_{eff} puzzle, see talk on correction to CDF results (AS. M. Seymour, M. Myska).

Thank you for the attention!

Backup



√s = 7 TeV
w/o CR
SCR
PCR
1/n dn/dM_cl/GeV^-1
M_cluster [GeV]
√s = 7 TeV
1/n dn/dM_cl/GeV^-1
M_cluster [GeV]



default clusters
h-type clusters
i-type clusters
n-type clusters
after reconnection
h-type clusters
i-type clusters
n-type clusters
1/n dn/dM_cl/GeV^-1
M_cluster [GeV]
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
2
4
6
8
10
12
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^-8
10^-9
10^-10
10^0
10^1
10^2
10^3
10^4

Energy extrapolation tuning

"Single" UE tune for different energies

$\sqrt{s}$/GeV	MB	UE	MB+UE
900	✓	$\uparrow$	$\sim$
1800	?	✓	?
7000	$\sim$	$\downarrow$	$\sim$

What I mean by "∼" (this is UE tune so MB was not used):